The international Facility for Antiproton and Ion Research FAIR: Challenges and Opportunities

C. Höhne

GSI, Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt, Germany

Abstract. The status of FAIR, the planned "Facility for Antiproton and Ion Research", is presented in this contribution. FAIR will be a world unique particle accelerator facility to be built as a joint project by - as of today - 16 member countries. FAIR, which is planned for construction adjacent to the GSI site in Germany, is an integrated system of particle accelerators, 2 superconducting synchrotrons and 8 storage rings, which will provide high energy and high intensity beams of ions from hydrogen to uranium with unprecedented quality and in full parallel mode. In addition highest luminosity secondary beams of rare isotopes and beams of antiprotons will be available. FAIR will combine physics research topics from different communities, i.e. nuclear physics, hadron physics, heavy-ion physics, plasma physics, atomic physics and accelerator development. Details of FAIR and the physics projects will be presented in this contribution.

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OVERVIEW ON FAIR

The international Facility for Antiproton and Ion Research (FAIR) is planned for construction adjacent to the GSI Laboratory in Darmstadt, Germany. Figure 1 shows the foreseen accelerator complex comprising two superconducting synchrotrons with rigidities of 100 Tm and 300 Tm (SIS100/300) and a set of ion storage and cooler rings with in-ring experiments or adjacent experimental setups. SIS100 will deliver high intensity primary ion beams, i.e. up to 10^{12} $^{238}U^{28+}$ /s with energies up to 2 GeV/nucleon; respectively 10^{9} $^{238}U^{92+}$ /s with 35 GeV/nucleon at maximum for SIS300. Primary proton beams with energies up to 90 GeV are provided with intensities up to $2 \cdot 10^{13}$ /s. These high primary beam intensities allow for high intensity secondary radioactive beams and rare isotopes or antiprotons which can be stored and cooled for further experiments. The rare isotope beams will show factors up to 10000 increased intensity compared to the existing GSI facility. In the High-energy Storage Ring (HESR) 10^{11} antiprotons with a beam energy range of (0.8-14.5) GeV are stored and cooled. The ring system will provide parallel operation of up to 5 experimental programs. With these features FAIR goes to the high intensity frontier therefore measurements will be performed of many rare events and observables never been studied so far. FAIR will serve a large science community with more than 3000 users and will allow for research programs in nuclear structure and nuclear astrophysics, hadron physics, the study of compressed baryonic matter, plasma and atomic physics. The first three QCD related research topics will be briefly introduced in the following sections. In atomic physics exotic objects such as highly charged Rydberg atoms will be studied. Plasmas similar to those in the interior

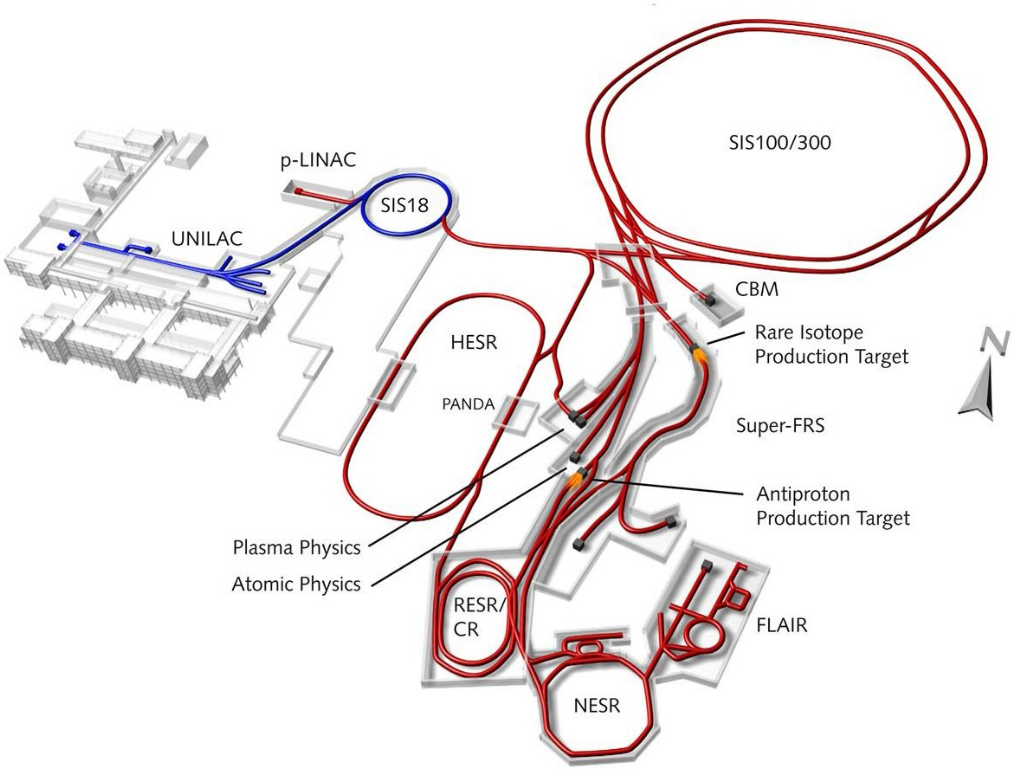

FIGURE 1. Overview of the FAIR accelerator complex.

of Jupiter and the sun can be created and investigated by using bunched compressed high intensity ion beams stopped in a block of material. A broad overview on the FAIR facility and its research programs can be found in [1], details are addressed in [2]. In addition to this basic research program, applications and spin-offs like radiobiological risk assessments for manned space missions will be studied at FAIR.

The FAIR project has been started in November 2007 and the Company FAIR GmbH will be created early summer 2009. Partial start of the operation is expected in 2014.

Accelerator R&D

The planned operation of FAIR relies strongly on an excellent performance of the accelerator complex. In order to provide the ring complex adjacent to the SIS100 with beams, rapidly cycling superconducting magnets ($dB/dt \sim 4$T/s) are being developed. First prototypes have already been delivered and are currently tested at GSI. The special challenge in the construction of the SIS300 magnets are the superconducting curved coils with 300 Tm bending power. In order to achieve the high beam intensities and avoid beam losses, special effort is made to establish an excellent dynamical vacuum and special coatings of the beampipe are applied. All developments are performed in close collaboration with external partners and industry.

NUCLEAR STRUCTURE AND ASTROPHYSICS (NUSTAR)

In the nuclear structure and astrophysics program nuclei far off stability will be investigated in detail using the Superconducting Fragment Separator (Super-FRS), the Collector Ring (CR), and the New Experimental Storage Ring (NESR). These investigations will allow to address the complex nucleon-nucleon force and its underlying QCD structure, e.g. by studying new magic numbers far off stability and nuclei with proton/neutron skins or halos. Theses studies should also pave the way for a theoretical framework with predictive power for nuclei beyond experimental reach. In astrophysics, the investigation of nuclei far off stability allows to address questions connected to the nucleosynthesis in stars and supernovae and to the origin of heavy elements, to the physics of stellar explosions and of compact objects such as neutron stars and the explosions on their surfaces (x-ray bursts).

Intensive rare isotope beams will be produced by in-flight projectile fragmentation or fission and selected by the Super-FRS. Due to its enlarged phase space coverage and thus transmission probability, intensity gains of up to 10000 are achieved compared to the existing FRS at GSI in combination with the higher beam intensities of FAIR. Detailed investigations of the produced rare isotopes can be performed in a high energy branch for the shortest lived nuclei. Furthermore, a ring branch (CR, NESR) with internal targets and a low energy branch with the possibility to stop and capture the isotopes in traps are available for additional measurements.

HADRON PHYSICS WITH BEAMS OF ANTIPROTONS (PANDA)

The PANDA in-ring experiment at the High Energy Storage Ring (HESR) will perform precision measurements of masses and lifetimes of hadrons and gluonic excitations (hybrids, glueballs) as shown in figure 2 (left). In particular the charm sector can be fully explored with the range of antiproton beam energies provided by the HESR. In $\overline{p}+A$ collisions open and hidden charm will be investigated in cold nuclear matter. These measurements will allow to study the non-perturbative regime of QCD addressing

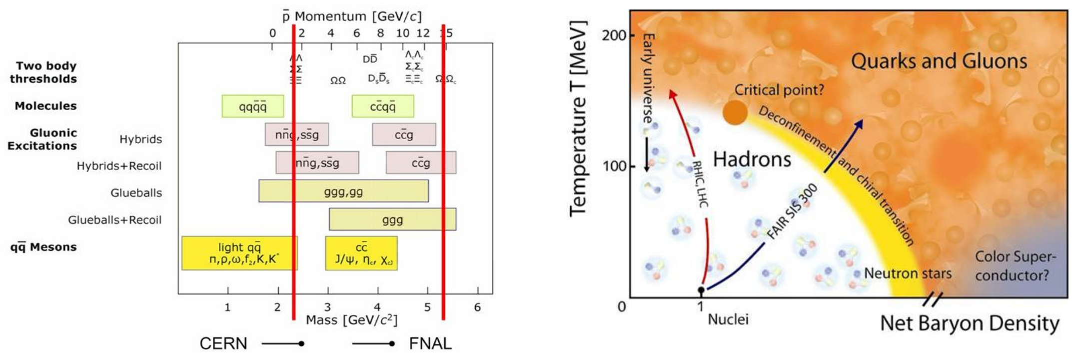

FIGURE 2. Left: Overview on the hadronic and gluonic excitations to be investigated in the PANDA experiment (region within red bars is accessible). Right: Artistic view of the QCD phase diagram. CBM will address the intermediate range where the critical endpoint is possibly located.

questions related to the quark confinement potential, self interactions among gluons, chiral symmetry breaking and the generation of hadron masses.

In the HESR up to 10^{11} antiprotons can be stored with energies from (0.8-14.5) GeV. A proton or nuclear target in PANDA will be realized as gas-jet, pellet or wire target. Using only stochastic cooling the HESR can be run in a high luminosity mode ($L = 2 \cdot 10^{32} \mathrm{cm}^{-2}\mathrm{s}^{-1}$) with a momentum resolution of $\delta p/p \sim 10^{-4}$. Adding electron cooling, the momentum resolution is increased to a few 10^{-5} with a Luminosity of al least $10^{31} \mathrm{cm}^{-2}\mathrm{s}^{-1}$ (high resolution mode). As in $p\overline{p}$ annihilations all states can be formed directly, the high momentum resolution allows for a high mass resolution of investigated hadronic and gluonic excitations.

BARYONIC MATTER AT HIGH DENSITIES

The Compressed Baryonic Matter experiment (CBM) will explore the QCD phase diagram (see fig. 2 (right)) in the region of moderate temperatures but very high net-baryon densities with $A+A$ collisions from (10-35) AGeV beam energy (45 AGeV for $Z/A = 0.5$). A detailed investigation of this region of the QCD phase diagram allows to search for expected structures such as the first order phase transition between hadronic and partonic matter, the critical point, and the onset of chiral symmetry restoration. The investigation of the nuclear equation of state at (5-10)ρ_0 will provide important input for the understanding of the interior of neutron stars in which similar densities might be reached.

As FAIR will provide beam intensities up to 10^9 ions/s rare observables such as charm production at threshold and dileptons become available. Interaction rates up to 10 MHz are foreseen posing large experimental challenges to CBM. Extremely fast and radiation hard detectors are being developed and will be read out by free-streaming readout electronics. In order to achieve the necessary high-speed online event selection the upcoming many core CPUs will be used for online tracking and vertex searching.

SUMMARY

The upcoming international FAIR facility will provide a world unique environment for future basic research in the fields of nuclear structure and nuclear astrophysivs, hadron physics, high density baryonic matter, plasma physics and atomic physics. Its key characteristics are the production of high intensity primary and secondary beams of utmost precision. The layout of the accelerator complex allows for an efficient parallel operation of up to 5 programs. The construction is planned in three phases until 2016 from when on more than 3000 users per year are expected performing fundamental studies of strongly coupled many body systems.

REFERENCES

1. Nuclear Physics News, Vol. 16 No. 1, 2009.
2. FAIR baseline technical report, 2006, `http://www.gsi.de/fair/reports/btr.html`.